

# CHANGING THE LANDSCAPE OF CIVIL AVIATION

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## Abstract

NASA is undertaking several bold new initiatives to develop revolutionary technologies that will change the landscape of civil aviation. These technologies span the civil aviation fleet from general aviation to large subsonic and supersonic aircraft and promise to bring an era of new aircraft, lower operation costs, faster more direct flight capabilities, more environmentally friendly aircraft and safer airline operations. These initiatives have specific quantified goals that require technologies well beyond those currently being developed creating a bold new vision for aeronautics. Revolutionary propulsion systems are enabling for these advancements. An overview of the new national aeronautics goals for civil aviation is given and the pivotal role propulsion technologies play in environmental compatibility, affordable air travel and revitalization of general aviation is explored.

## Overview of New National Goals

NASA and the Administration have recently announced ten bold new national aeronautics and space transportation goals. These goals fall under three major "pillars" or groupings: Global Civil Aviation, Revolutionary Technology Leaps, and Access to Space. The first two pillars which address eight goals that directly impact civil aviation are briefly described. A more complete overview of all the goals can be accessed on the internet at <http://www.aero.hq.nasa.gov/>.

### Global Civil Aviation

The goals under the first pillar, Global Civil Aviation, address the highest priority needs to ensure continued U.S. leadership in large subsonic commercial aviation. To preserve our Nation's economic health and the welfare of the traveling public, NASA must provide high risk technologies for safer, cleaner, quieter, and more affordable air travel. Figure 1 summarizes the national goals under this pillar.

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The current national aviation system is the safest form of transportation available today. With over 15 million departures per year and on the order of 20 hull loss accidents during the same period, the accident rate statistics show a safe system with a very large capacity. The projected tripling of global air traffic in the next 20 years means that even the currently low accident rate will yield unacceptably high numbers of fatal accidents as shown in Figure 2. In partnership with the FAA, NASA is committed to the goal of reducing the aircraft accident rate by a factor of five within ten years, and by a factor of ten within twenty years. This is an ambitious goal which must span the full range of technologies across accident prevention, accident mitigation, and aviation system wide innovations.

U.S. leadership in improvements in environmental compatibility are critical to address the growing concerns about emissions and noise from aircraft. Increased urbanization around airports and public awareness are powerful forces driving the need for reductions in the environmental impact of aircraft. There are two major goals. The first is to reduce emissions of future aircraft by a factor of three within 10 years and by a factor of five within 20 years. The second goal is to reduce the perceived noise levels of future aircraft by a factor of two from today's subsonic aircraft within 10 years and by a factor of four within 20 years.

In 1974 the U.S. enjoyed over 90 percent of the world market share in large commercial transport manufacturing. Today, that market share has shrunk to about 70 percent and the U.S. faces escalating international competition. One key to ensuring continued U.S. dominance in this economically critical market is to reduce the billions of dollars lost annually by airlines through delays and lost productivity due to weather delays and congestion. NASA has committed to tripling the aviation system throughput in all weather conditions within 10 years. The other key barrier to holding or increasing U.S. market share is to

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dramatically reduce the time and cost to develop, produce, and certify U.S. aircraft and engines to reverse the trend of increasing aircraft ownership and operating costs. The second goal is to reduce the cost of air travel by 25 percent within 10 years and by 50 percent within 20 years.

#### Revolutionary Technology Leaps

While Pillar One addresses challenges for the existing global civil aviation fleet, Pillar Two aims to give the U.S. a commanding lead in new markets which have the potential to dramatically change the current fleet by developing revolutionary aircraft, propulsion systems, and critical design tools. Two new revolutionary aircraft are envisioned at opposite ends of the speed spectrum: a new affordable, environmentally friendly supersonic commercial transport and revolutionary general aviation aircraft. The goals under Pillar Two are summarized in Figure 3.

Breaking the barriers to a commercially viable High Speed Civil Transport (HSCT) to open markets to the Far East and Europe is quantified in the first goal: to reduce the travel time to the Far East and Europe by 50 percent within 20 years at today's subsonic ticket prices. The key to the HSCT is quiet, clean, affordable supersonic engines. The technologies critical to the HSCT are being developed under NASA's High Speed Research program which has been widely reported most recently in Reference 1.

In 1978 the U.S. general aviation industry market was at almost 18,000 aircraft per year. In 1996, this market had fallen by a factor of over 100 to about 1100 aircraft per year. Recent tort reform has set the stage for a major revitalization in general aviation. Current barriers are now principally technical as the industry is relying largely on 40 year old technology. NASA has recently begun a new General Aviation Propulsion (GAP) program to develop revolutionary turbine and piston engines to enable unprecedented general aviation aircraft performance. The goal is to enable the delivery of 10,000 aircraft annually within 10 years and 20,000 aircraft annually within 20 years.

The eighth goal addresses a pervasive barrier across all three pillars and their goals. All of the dramatic goals will require more cost effective technology development in today's budget constrained environment. The next generation of design tools and experimental aircraft will be needed to cost effectively develop technology with sufficient confidence to enable U.S. industry to transition these technologies into the products of the future. The NASA goal is to provide these design tools and experimental aircraft to increase design confidence and cut the development cycle time for aircraft in half. Reference 2 describes the Numerical Propulsion System Simulation which is a critical element in achieving this goal.

These bold goals have the general support of the U.S. industry and NASA government partners. In conducting these new national initiatives, NASA is adopting new ways of doing business with closer working relationships across the private and public sectors. NASA will be providing the expertise and resources that best match its mission and capabilities and relying on its partners to play their critical part. If successful, the civil aviation landscape will look radically different in the next decade. Three areas are explored in more depth: environmental compatibility, affordable air travel, and revitalized general aviation.

#### Environmental Compatibility

The goals for environmental compatibility will require technologies well beyond those being currently developed in the Advanced Subsonic Technology Program (AST) for regional and large commercial aircraft for both emissions and noise. The projected increase for emissions and noise due to increased air travel outstrips reductions in fuel consumption and noise reductions currently being developed.

#### Emissions

The emissions of aircraft are directly dependent on the fuel efficiency and weight of propulsion systems and the aerodynamic efficiency and weight of aircraft. Figure 4 shows that the steady increase in fuel efficiency results in higher revenue passenger miles per gallon of fuel. This improvement trend will continue if current NASA programs and those addressing the affordable air travel goal are implemented.

There is general agreement that the tripling of air traffic over 20 years will result in a significant increase in aviation fuel usage in spite of the improvements in fuel efficiency. The current emissions goals in the AST program begin to meet this challenge. The national goals stretch beyond the AST goals to continue to meet the continuing environmental challenge. Reference 3 is a good overall review of the global atmospheric effects of aviation.

Table I compares the national NOx reduction goals with those in AST and requires further explanation because the combustor technologies are not developed to the same level.

Table I.— National NOx Emissions Goals  
Exceed AST Goals

	<u>3 yrs</u>	<u>5 yrs</u>	<u>10 yrs</u>	<u>20 yrs</u>
AST	-50%	-70%		
National Goals			-67%	-80%

The AST program will demonstrate large and regional engine combustors at 50% lower NOx levels than the 1996 ICAO limits with comparable cruise NOx emission reductions and no increases in other takeoff emission constituents such as CO, smoke, and unburned hydrocarbons. AST will also develop low-emission combustion technology, design methodology and databases to understand additional emission reductions of 70% lower NOx. Reference 4 gives additional information on the AST program.

The national goals pick up where AST leaves off and intend to demonstrate combustors at a 67% lower NOx levels with a level of technology readiness that permits technology transfer to products. This 67% NOx reduction level is a small decrease in the goal due to the compromises necessary in a practical combustor design. The 20 year goal reduction of 80% is a farther term ambitious stretch goal. In addition to reductions in NOx, the national goals intend to include significant reductions in other emittants such as CO<sub>2</sub>, aerosols, and particulates which reflect the growing concern over environmental emissions other than NOx.

Recent media attention has heightened public awareness and concern over the impact of airports on urban pollution and air quality. Concerns are raising over CO<sub>2</sub> and the green house effect with its resultant global warming. The effect of aerosols and particulates on air quality and cloud formation are gaining attention in both professional, regulatory, and political arenas. All of these forces are working to increase regulation and economic incentives to reduce aircraft emissions. In addition, the total emissions of the current fleet needs to be determined to a much greater degree of fidelity to ensure a good baseline against which progress can be measured.

#### Noise

Unlike emissions, the noise impact of the current fleet is well documented in recently published studies such as Reference 5. Figure 5 shows the significant progress in noise reduction of aircraft over fifty years from Reference 6. The growth of air traffic presents a similar challenge in reducing community noise. Despite the introduction of quieter Phase III aircraft, noise will increase near airports as air traffic triples over the next 20 years. Coupled with the increased urbanization around airports and airport expansion, noise will increase as a barrier to air transportation.

Figure 6 shows that the 10 year national goal of 2x noise reduction can be achieved in the currently planned AST program with its -10dB goal for airframe plus engine and nacelle noise reductions but that the 20 year goal

requires an additional 10dB reduction. Figure 7 illustrates the impact of traffic growth on the fleet daily airport noise levels (DNL). Aircraft noise must be reduced about 20 dB to achieve a no community noise impact level. This will require quieter engines and airframes as the noise of the airframe structure will be a greater factor than before.

The no impact boundary means that the noise footprint of aircraft would fall entirely within the airport boundaries of most major airports. Figure 8 illustrates the noise impact areas for JFK shrinking from a 1992 baseline of 25.2 square miles to within the airport boundary.

The benefits of such noise reductions extend far beyond the elimination of community noise impact. Such reductions would eliminate noise curfews and noise abatement routes. One estimate of the projected time savings from elimination of noise abatement routes is 2 minutes per flight segment. This is about one half of the savings projected for unrestricted flight routing and could save airlines billions of dollars per year.

NASA is in the very early stages of defining the goals in more detail and of exploring productive approaches to meeting these goals. Workshops are being planned that promote broad participation in addressing aviation environmental issues and the identification of revolutionary technologies that can address these challenges. NASA in partnership with U.S. industry and other government agencies is working to continue to responsibly address aviation's environmental challenges.

#### Affordable Air Travel

While the Aeronautics Enterprise is still developing program plans to address the goals of reducing the cost of air travel by 25% within 10 years and by 50% within 20 years, there is a credible approach identified that shows how this goal might be achieved. The underlying metric is the cost per available seat mile (ASM). Reducing the cost per ASM can be broken down into three principal areas:

- 1) reduced ticket prices from airline efficiencies and market pressures
- 2) improved productivity from increased load factors and utilization
- 3) reductions in Direct Operating Costs plus Interest (DOC+I)

It is believed that airline operating efficiencies and market pressures will continue to reduce fares by about 1% per year independent of any aircraft cost reductions as shown in Figure 9. In addition, the application of advanced

information technology developed by NASA to fleet scheduling and location could increase load factors and utilization by about 10% each. The total reduction in cost per ASM from these factors will equal about 25% or about half of the goal.

The cost drivers for a typical long-range passenger mission is shown in Figure 10. It is clear that NASA research and technology can strongly influence DOC+I which account for about 55% of these costs. Therefore, the other 25% of the reduction in cost per ASM needs to be achieved by reducing DOC+I by 50% because DOC+I is only half of the ticket price equation.

One can now begin to assign sub-goals to various elements of the aircraft. One example of such a sub-allocation is:

	DOC+I
Aerodynamics	-10%
Structures and Fabrication	-15%
Propulsion Efficiency	-15%
Systems	-10%
Total	-50%

It should be noted that each of these elements are influenced by many subsystems. For example, the propulsion design and operational requirements strongly impact aerodynamics and systems as well as propulsion efficiency.

One can now further break down these sub-allocations and begin to identify specific sub-goals and technologies that could have the desired reductions. Figure 11 shows the impact of engine systems on aircraft DOC+I and three different scenarios that could produce a 15% DOC+I savings. Some key technology challenges clearly fall out:

- 1) integrated design process to reduce cycle time and cost
- 2) low part count and improved component efficiency to reduce fuel consumption, acquisition cost and enhance reliability
- 3) smart components and systems to build in reliability to reduce maintenance costs.

Figure 12 shows some of the revolutionary technologies required to meet such aggressive goals. It should be noted that the ultra low noise/low NOx technologies are included because noise and emissions are strong economic drivers. The requirement to fly noise abatement routes, reductions in operating hours by noise curfews, and landing fees are examples of the direct economic impact of noise. However, reductions in noise and emissions are discussed under the environment national

goal and the economic benefit of these reductions are not included in the reductions in cost/ASM.

The technologies shown in Figure 12 are not simple extensions of even today's advancements but will require a rethinking of the entire propulsion system from concept to field maintenance. For example, one might need to cut development time by at least a year on top of reductions already achieved and Mean Time Between Removals (MTBR) by a factor of 5.

### General Aviation Revitalization

While much of the previous goals have focused on large commercial aircraft that have the largest impact on the traveling public and on U.S. balance of trade and jobs, no discussion on changing the landscape of civil aviation would be complete without addressing general aviation. Figure 13 quantifies the dramatic drop in the delivery of new light aircraft from 18,000 in 1978 to about 1100 in 1996 as well as the new national goal of delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years.

With the recent passage of tort reform, the general aviation market is posed for tremendous growth in the U.S. and abroad. The current general aviation fleet is old and there is a large 'latent' demand for aircraft. In addition, there is a large potential world market and overseas industries are positioning themselves to get into this market.

To meet this "window of opportunity" to revitalize general aviation industry in the U.S., NASA has funded two principal programs: the General Aviation Propulsion (GAP) program and the Advanced General Aviation Technology Evaluation (AGATE) program. AGATE focuses on the aircraft structures, cockpit modernization, icing protection systems, and integrated propulsion controls among other areas and has been widely reported. GAP is a new program started in 1997 to develop and demonstrate affordable revolutionary aircraft propulsion systems by the year 2000 to replace the largely forty year old propulsion technologies that currently power light aircraft.

Two propulsion systems will be developed for 4 to 6 seat aircraft: a new turbine engine and an intermittent combustion (IC) engine. NASA has joined in a cooperative agreements with Williams International for the turbine engine and with Teledyne Continental for the IC engine development. The specific goals for the propulsion systems are listed in Table II. It is clear that low cost is the primary goal of the program but that low noise, low weight, good fuel consumption, and high reliability are also key goals.

Table II.— GAP System Goals

	<u>IC</u>	<u>Turbine</u>
Cost	-50%	-90%
Maintenance Cost	-50%	-90%
Specific Fuel Consumption	-25%	
Fuel	JP	
Emissions	meet expected standards for Yr2000	
Noise	meet expected standards for Yr2000	

The strategy to achieve the low cost includes simplified engine designs with a fraction of current number of parts, simplified assembly, fast prototyping, near net forming as well as high speed machining and advanced joining methods. FAA coordination and involvement is a high priority from the earliest stages to minimize certification costs and risks for the products that will developed after the GAP program is completed.

The turbine engine will be a 700 thrust class engine about 14 inches in diameter and 41 inches long. Figure 14 summarizes some of the key characteristics of this engine. The IC engine will be a 200 HP, two cycle, two stroke engine, that uses Jet-A fuel. Figure 15 summarizes some of the characteristics of this engine. Figures 16 and 17 are some initial projections of the level of cost reductions as a function of production rates that could be achieved for the engines and aircraft.

The excitement and vision for the future of the GAP program were evident last month at Oshkosh with the first public flight of the aircraft built to demonstrate the turbine engine in the year 2000. The aircraft, called the V-Jet, was built by Burt Rutan's Scaled Composites for Williams International. This event was a great start to this paradigm changing program.

#### Summary

The landscape of civil aviation will clearly dramatically change as NASA continues to make progress towards achieving the bold national goals recently announced. These changes span civil aviation from large commercial to general aviation aircraft and will revolutionize the global air transportation system. Propulsion technologies will play a pivotal role in enabling these advancements.

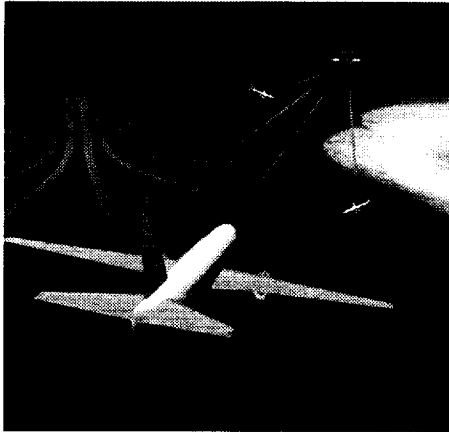
Realizing the new aeronautics vision for the nation will require closer coordination and teaming within NASA and with our U.S. industry customers and government partners. The next two decades promise to be a very exciting time in aeronautics.

#### Acknowledgements

The accomplishments and goals discussed in this paper are the result of the entire Aeronautics Enterprise team across NASA aeronautics centers and headquarters. I appreciate the opportunity on their behalf to present this view of the new NASA aeronautics vision. I would also like to acknowledge Sandra App, Kathryn Kafantaris, and Gloria Richards who were of special help in preparing the manuscript.

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*Seamless integration of air travel into the fabric of society: easily accessible, easily utilized, safe, affordable travel with minimal environmental impact. Customer demands will drive air travel systems, service, and products*

- ◆ Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of 10 within 20 years
- ◆ Reduce emissions of future aircraft by a factor of three within 10 years, and by a factor of five within 20 years
- ◆ Reduce the perceived noise levels of future aircraft by a factor of two from today's subsonic aircraft within 10 years, and by a factor of four within 20 years
- ◆ While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years
- ◆ Reduce the cost of air travel by 25% within 10 years, and by 50% within 20 years

Figure 1.—Goals for Pillar One: Global Civil Aviation.

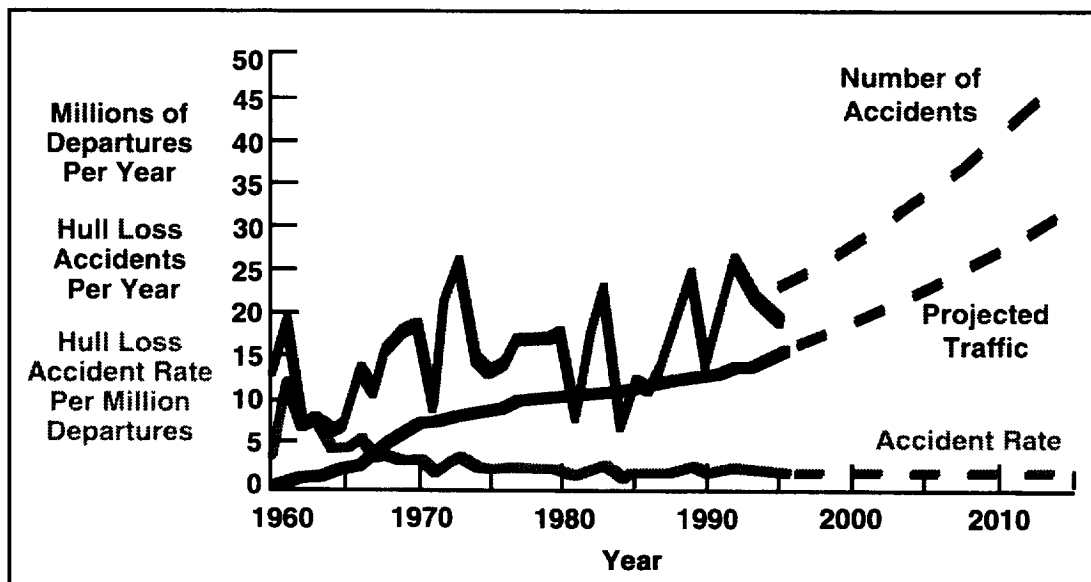


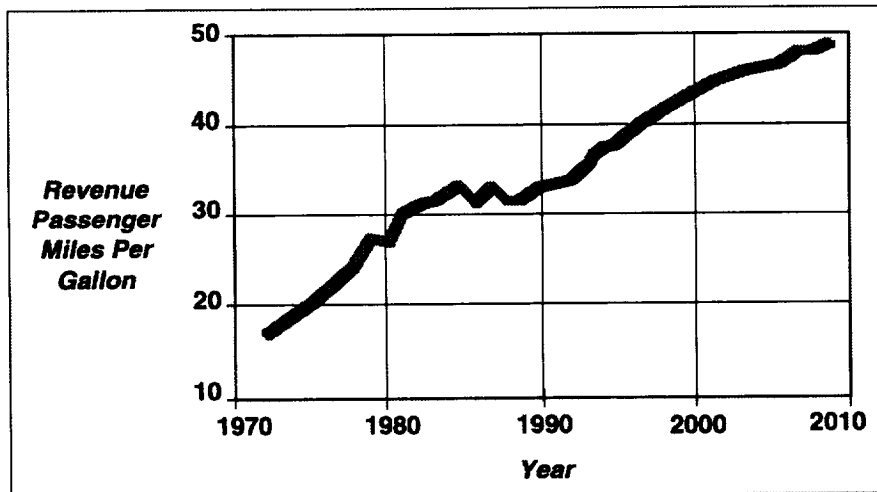
Figure 2.—Projected number of accidents with current accident rate.



*Research to revolutionize air travel: environmentally friendly transoceanic supersonic flights; technology to dramatically improve small aircraft designs, engine, and overall affordability*

- ◆ Reduce the travel time to the Far East and Europe by 50 percent within 20 years, and do so at today's subsonic ticket prices
- ◆ Invigorate the general aviation industry, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years
- ◆ Provide next-generation design tools and experimental aircraft to increase design confidence, and cut the development cycle time for aircraft in half

Figure 3.— Goals for Pillar Two: Revolutionary Technology Leaps.



- ◆ More Miles Per Gallon
- ◆ Less CO<sub>2</sub> and Other Emissions
- ◆ Cleaner Environment

Figure 4.— Continuous trend toward cleaner air.

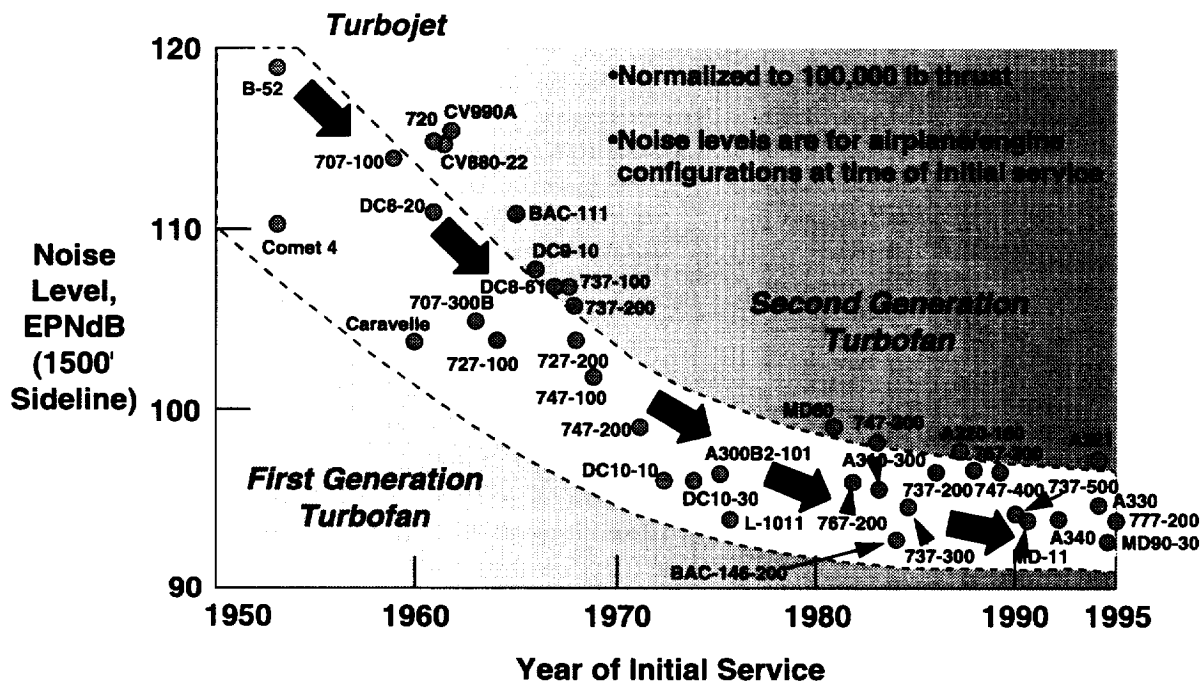


Figure 5.— Progress in noise reduction.

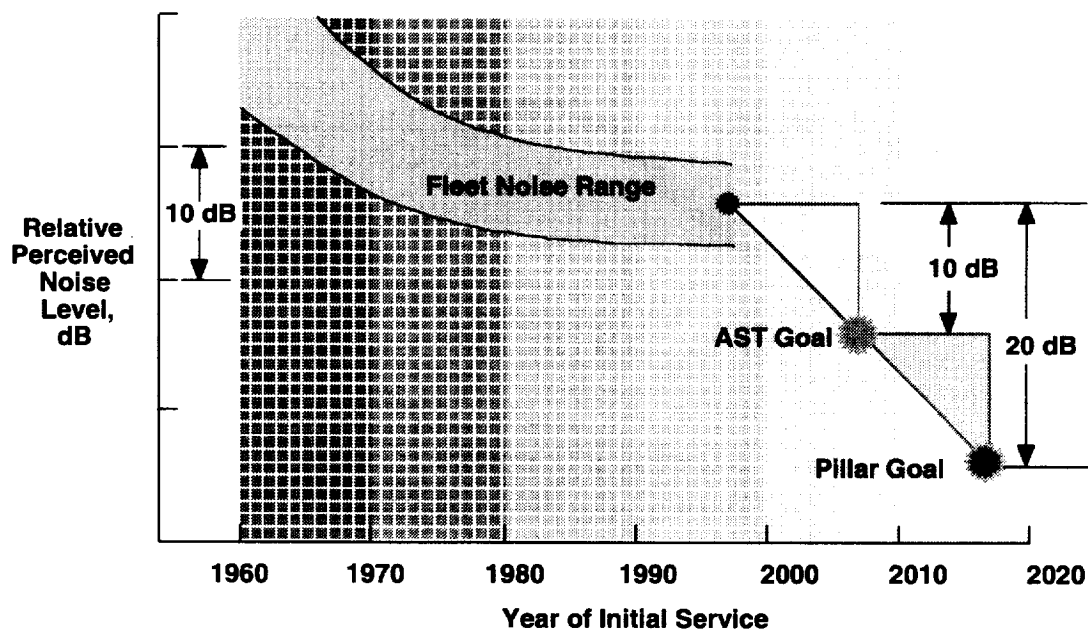


Figure 6.— Global civil aviation noise goals.



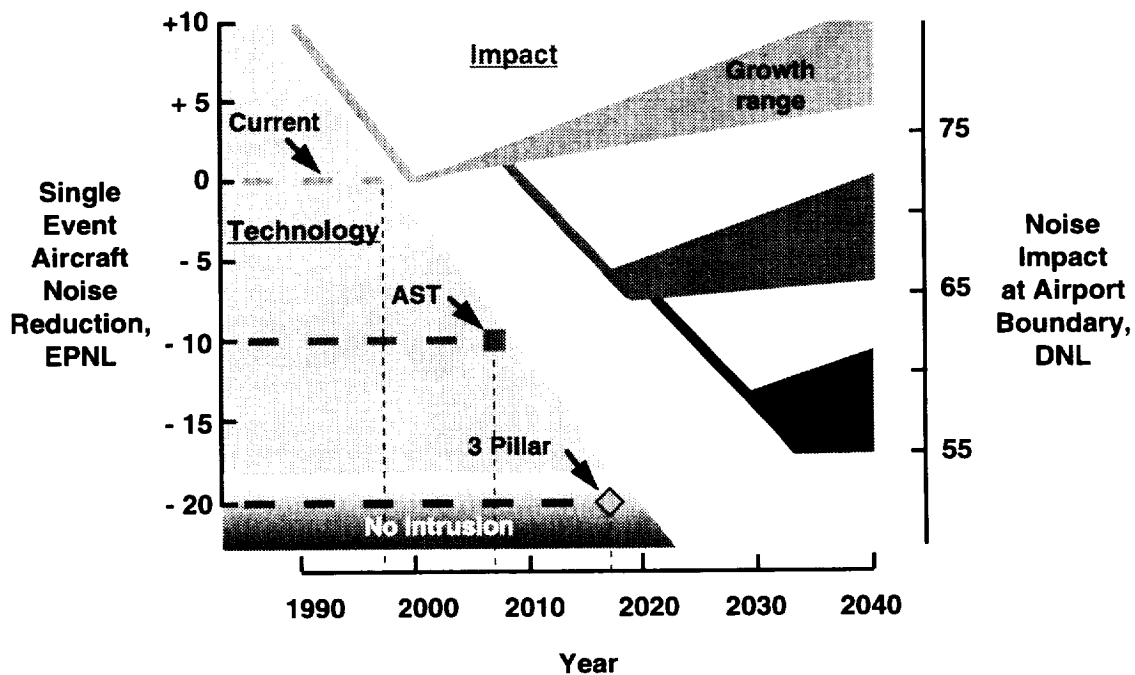


Figure 7.— Aircraft noise reduction and community impact projections.

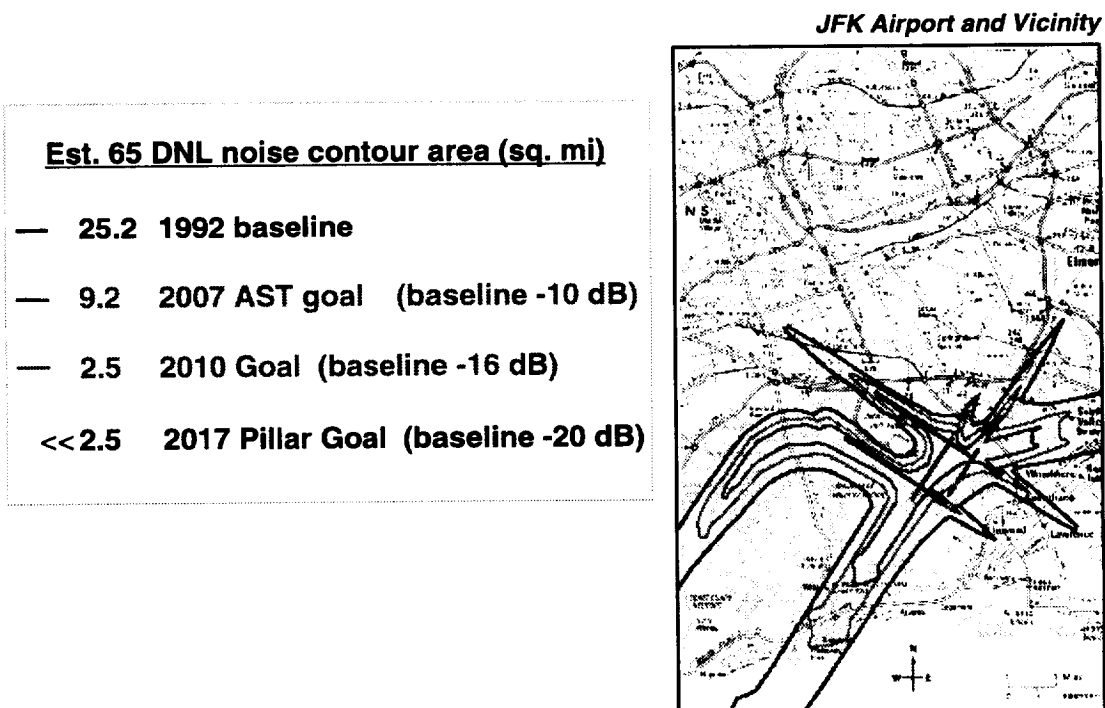


Figure 8.— Noise reduction to contain impact within airport boundaries.

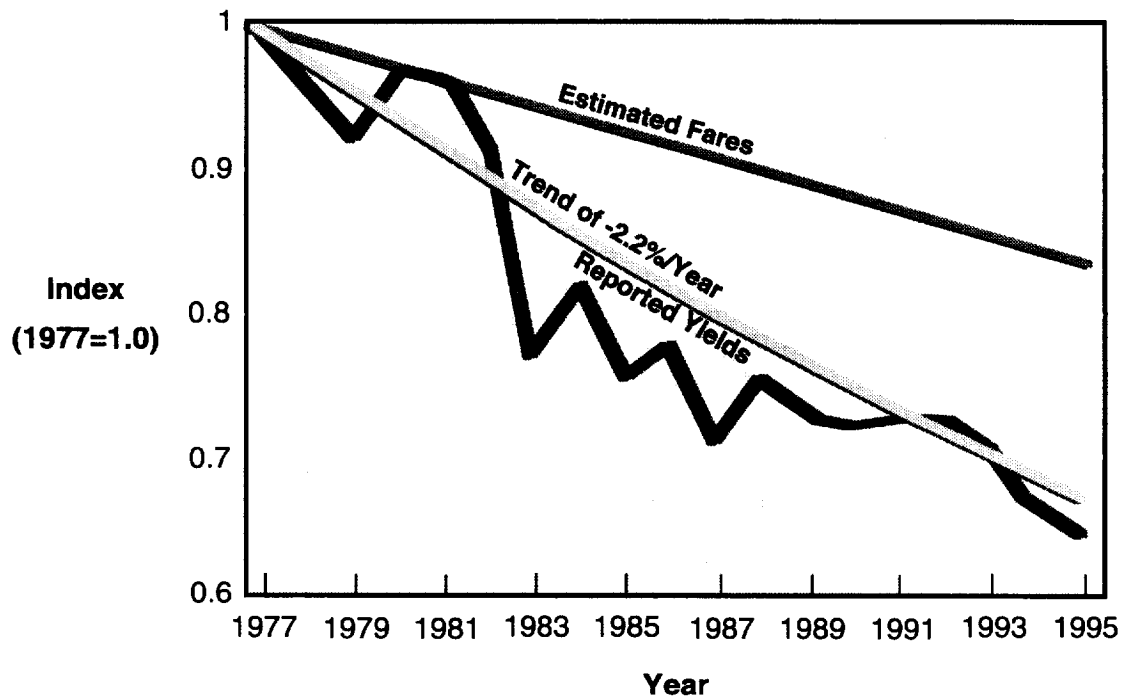


Figure 9.— Current airline ticket price trends.

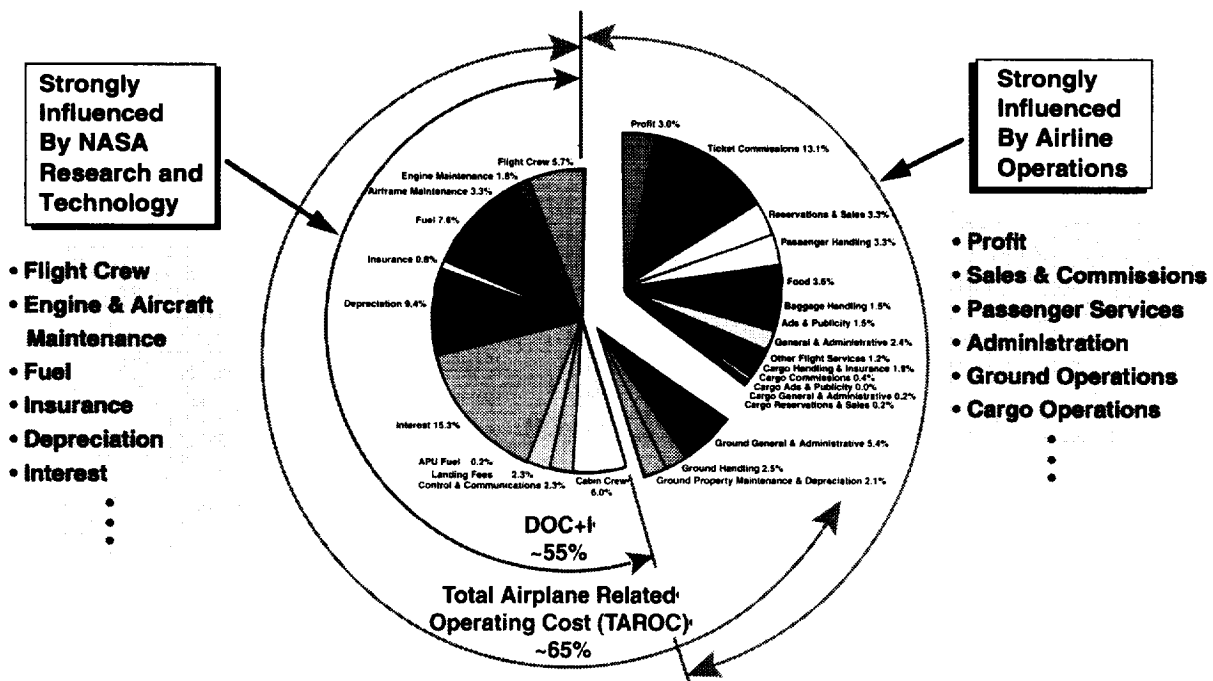


Figure 10.— Ticket price breakdown.

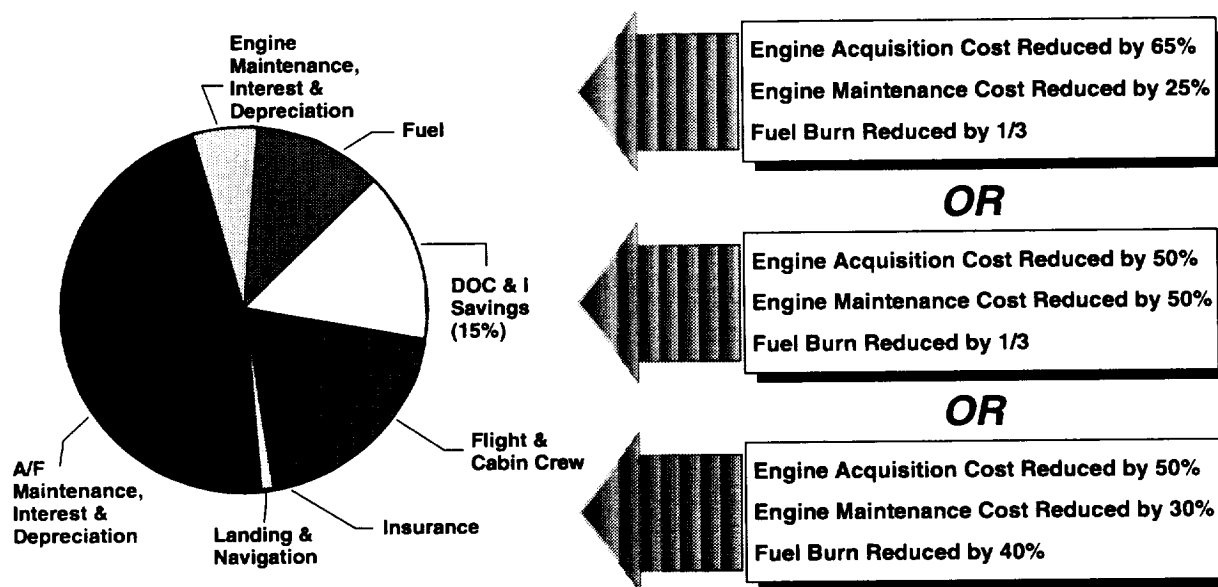


Figure 11.— Engine systems impact on aircraft DOC & I.

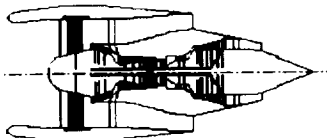
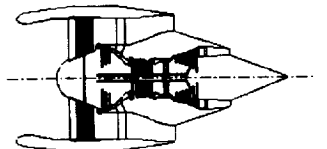
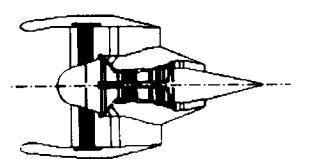
EIS Reference	Engine Sized for 70,000 lb Thrust	Characteristics
1996		<ul style="list-style-type: none"> <li>◆ 1996 Baseline</li> <li>◆ OPR = 38.5</li> <li>◆ 23% Cooling</li> <li>◆ WT = 24,738 lbs</li> <li>◆ SFC = 0.53</li> </ul>
2006		<ul style="list-style-type: none"> <li>◆ Low Noise/Low NOx</li> <li>◆ OPR = 50</li> <li>◆ 17% Cooling</li> <li>◆ WT = 17,155 lbs</li> <li>◆ SFC = 0.48</li> </ul>
2016		<ul style="list-style-type: none"> <li>◆ Ultra Low Noise/Low NOx</li> <li>◆ 2/3 Part Count</li> <li>◆ Smart Components and Systems</li> <li>◆ OPR = 60</li> <li>◆ 10% Cooling</li> <li>◆ WT = 13,981 lbs</li> <li>◆ SFC = 0.42 – 0.44</li> </ul>

Figure 12.— Revolutionary large subsonic engine technologies.

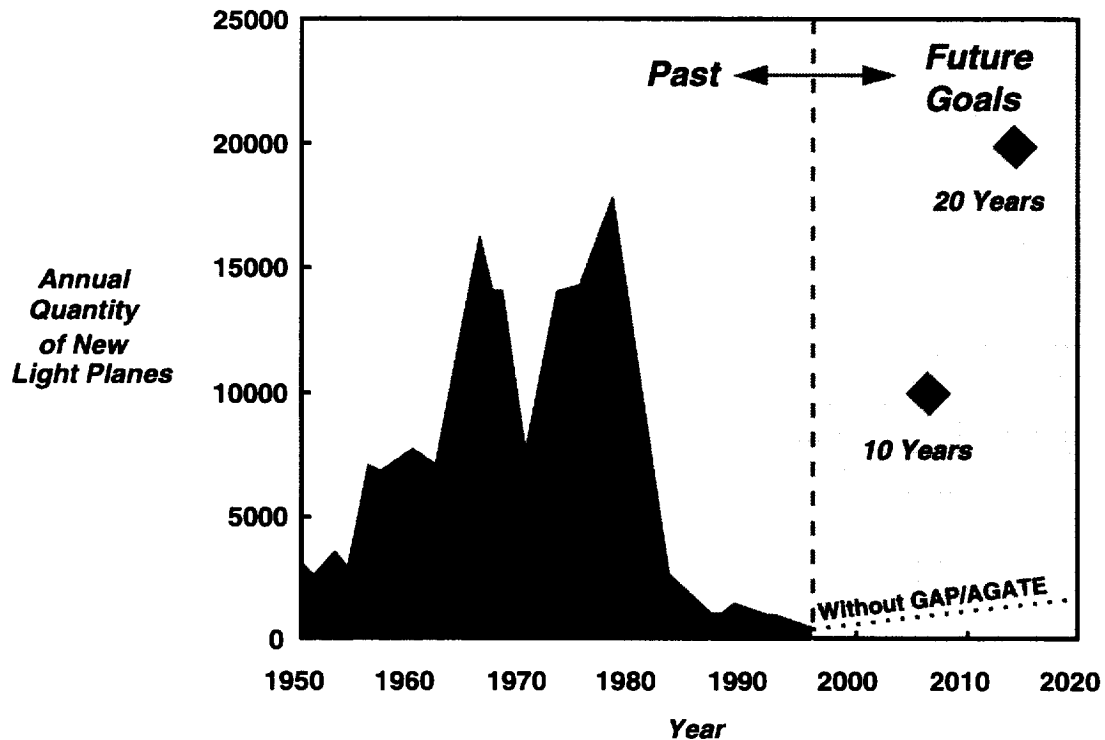


Figure 13.— Goals for revitalizing General Aviation.

- **High Bypass Ratio Turbofan**
- **700-lb Thrust Class with Growth Capability**
- **14-inch Diameter by 41-inch Length**
- **Weights less than 100 lbs**
- **Jet Fuel**
- **“Take-off to Landing” Fuel Burn Less Than Comparable Piston Engine Power Airplane**
- **Cost Competitive with Comparable Power Piston Engines of Today**
- **Single Lever Power Control**
- **Meets Future Exhaust Emissions and Noise Requirements**
- **Common Core Design For Turboprop & Turboshaft Versions**

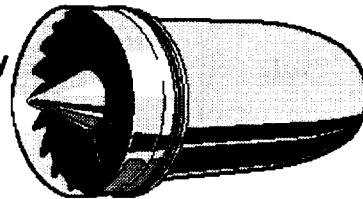


Figure 14.— GAP turbine engine characteristics.

### Teledyne Continental Motors CSD 283

- Compression Ignition Engine
- 2 Stroke, Direct Injection
- Liquid Cooled
- 200-bhp @ 2200-rpm
- 1/2 Cost Current Engines
- Jet Fuel
- Single Lever Power Control
- Electronic Diagnostics and Display
- Low Noise, Vibration and Harshness
- Meets Expected Future Emissions and Noise Requirements

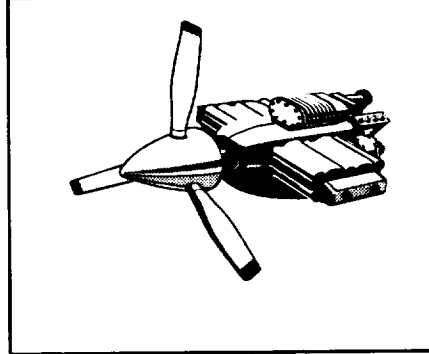


Figure 15.— GAP intermittent combustion engine characteristics.

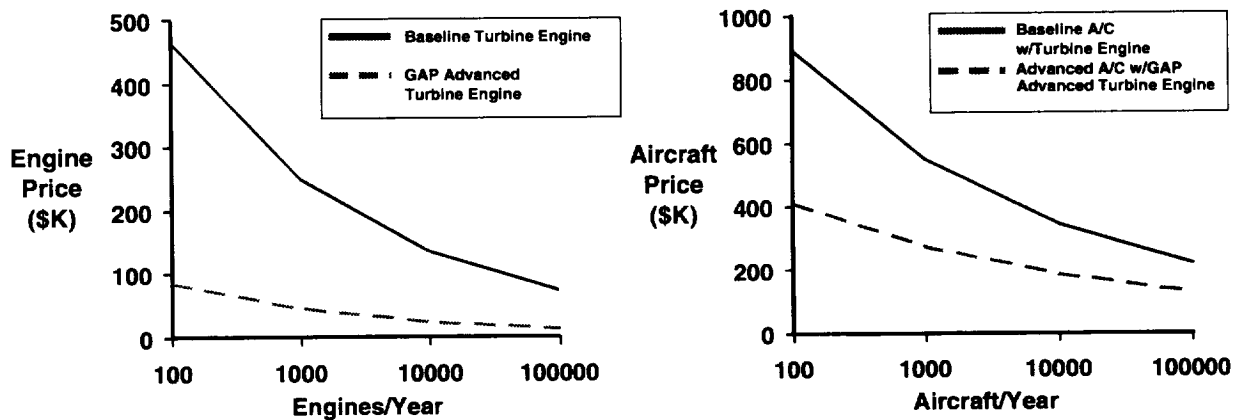


Figure 16.— Potential turbine engine and engine powered aircraft price reductions.

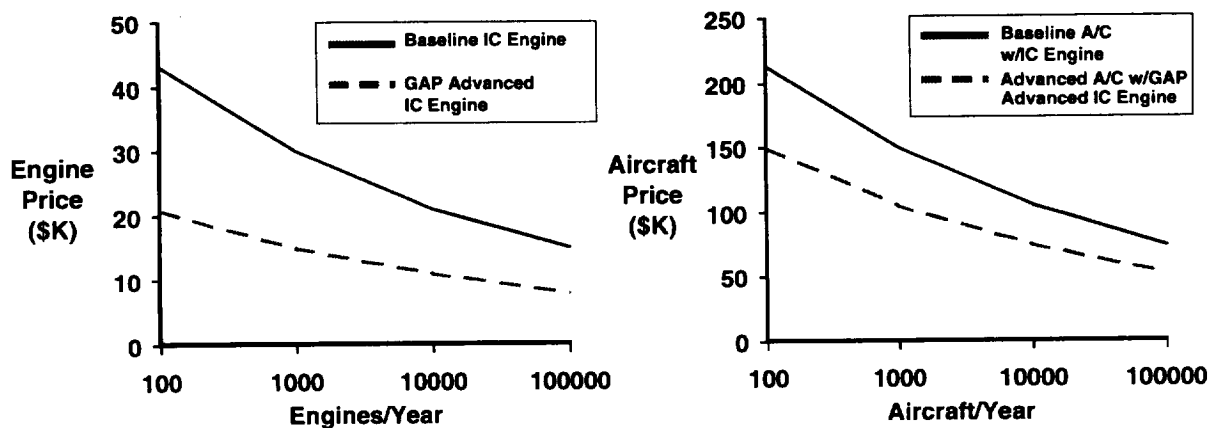


Figure 17.— Potential IC engine and IC engine powered aircraft price reductions.

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